Communicating with Mars During Periods of Solar Conjunction

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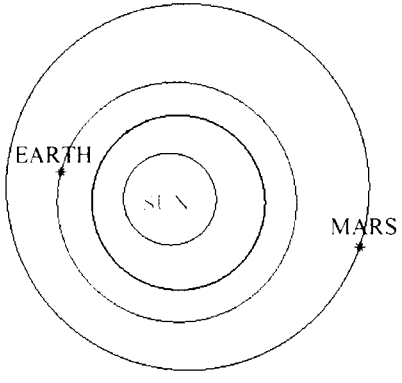
Background

- A reliable communications link between Mars and Earth will be required during the initial phase of the human exploration of Mars
- The direct communications link can easily be realized during most of the 780-day Earth-Mars synodic period, except when this link encounters increased intervening charged particles and noise during superior solar conjunctions
- The effects of solar charged particles are expected to corrupt the data signals to varying degrees.
- During superior solar conjunctions of interplanetary spacecraft, flight projects suspend or routinely scale down operations by
  - invoking command moratoriums
  - reducing tracking schedules
  - progressively lowering data rates.
- This study was conducted to determine to what extent and by what techniques communications may be maintained throughout Mars-Sun-Earth superior conjunction periods that could occur during early human Mars exploration

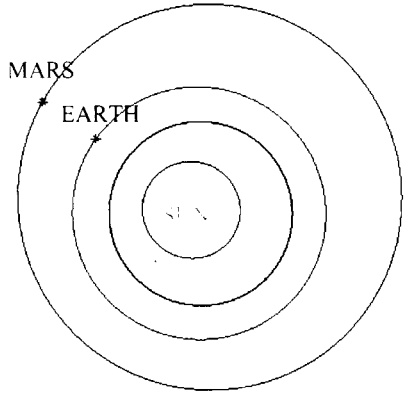
Earth – Mars Conjunction Geometries

Superior Conjunction



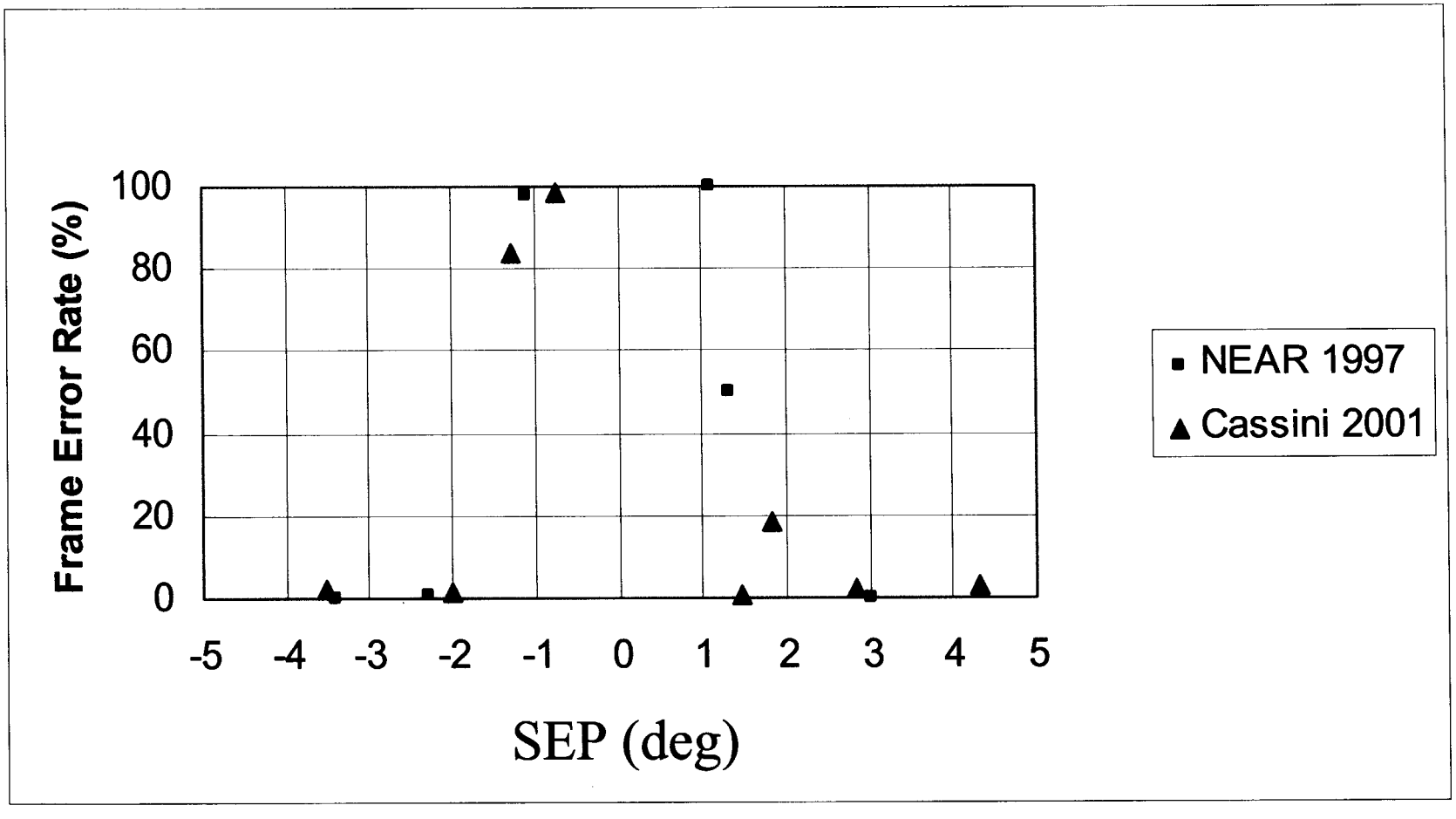
- Maximum Earth-Mars distance
- Weakest received signal
- Maximum solar charged particle effects
- From Earth, the Sun appears as a 0.264° radius disk
- From Mars, the Sun appears as a 0.175° radius disk
- The receiving antenna will pick up increased thermal noise as the SEP angle decreases

Inferior Conjunction



- Minimum Earth-Mars distance
- Strongest received signal
- Minimum solar charged particle effects
- From Earth, Mars will appear in the night sky at opposition. This link is expected to perform at its best during inferior conjunction
- From Mars, the Sun appears as a 0.175° radius disk

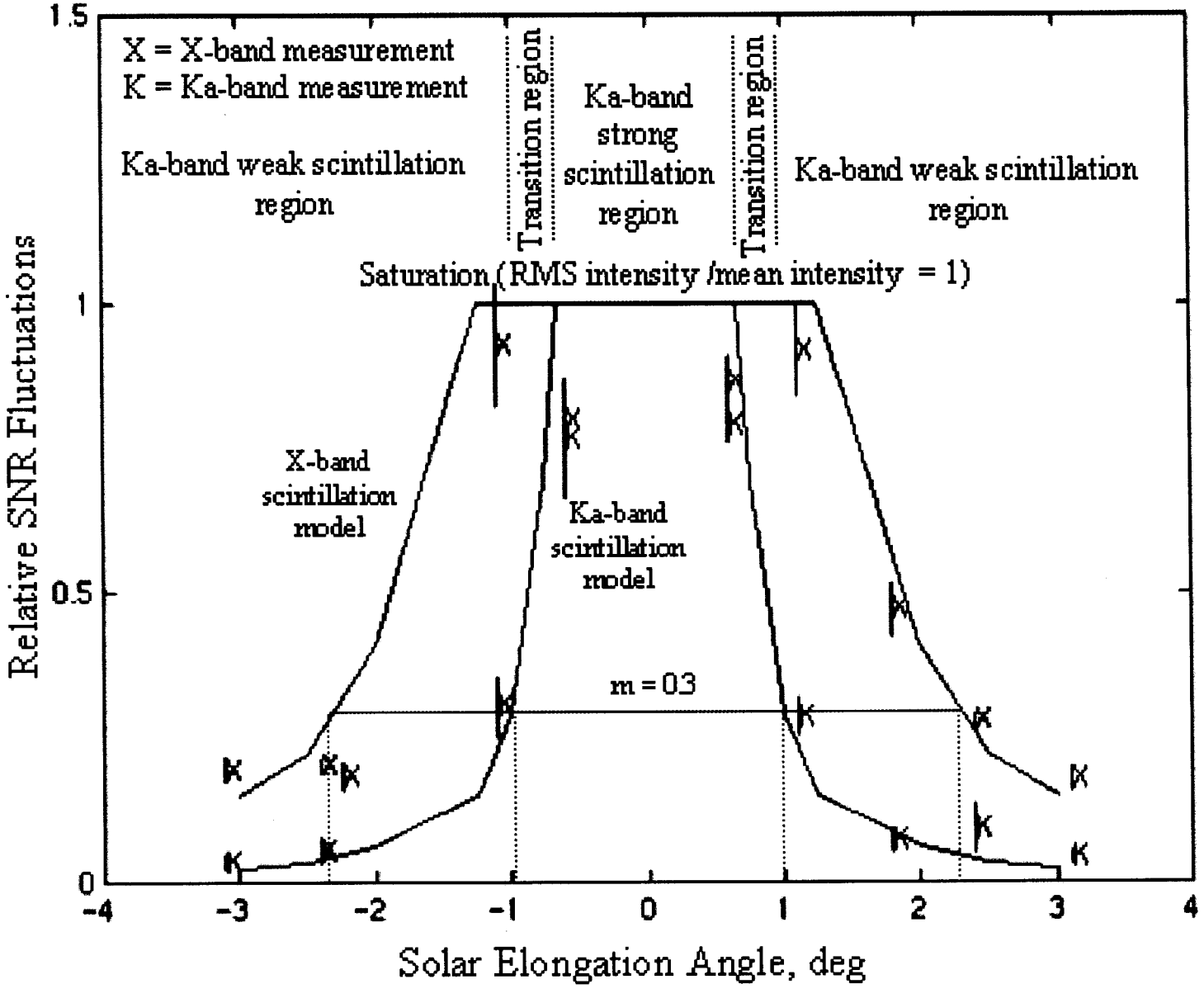
X-band Frame Error Rates Vs. SEP Angle



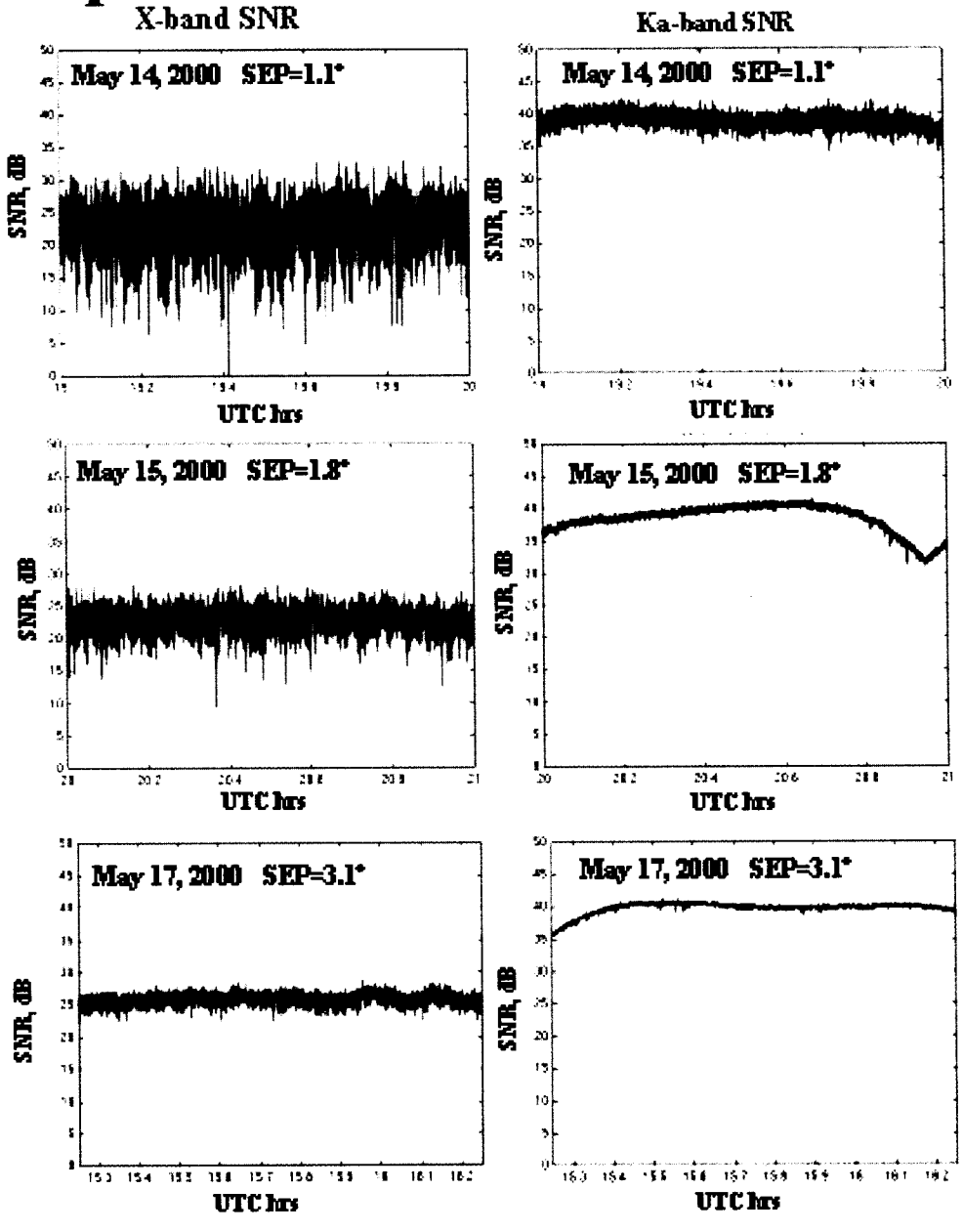
Expected Ka-band Telemetry Performance

- NEAR 1997 and Cassini 2001 solar conjunction X-band frame error statistics show good telemetry performance for SEP > 2.3°
- Solar conjunction carrier data measurements show that a scintillation index of m = 0.3 is realized at this SEP angle for X-band
- Assuming similar Ka-band telemetry performance can be realized at m = 0.3, the Ka-band scintillation model shows this occurs at SEP = 1°
- Thus, one should be able to obtain good telemetry performance down to 1° SEP angle using Ka-band

Scintillation Measurements and Models



Examples of Carrier SNR Fluctuations

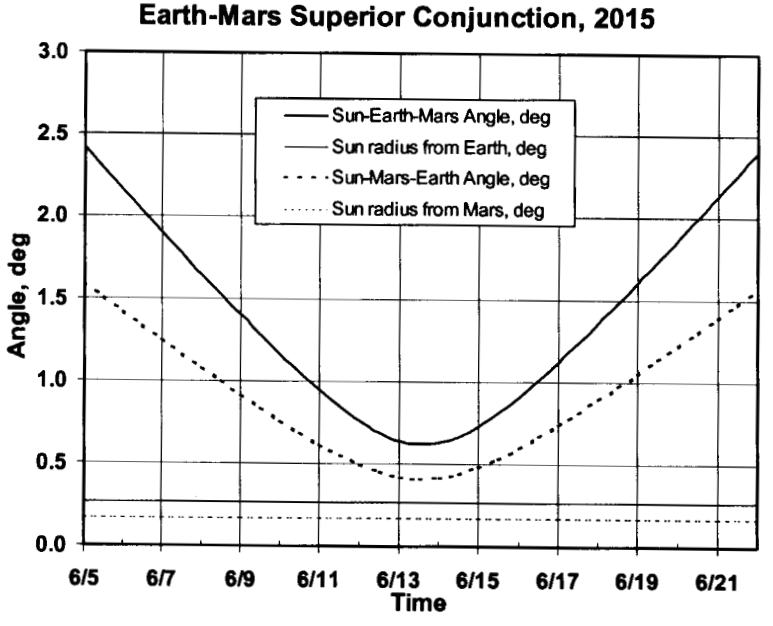


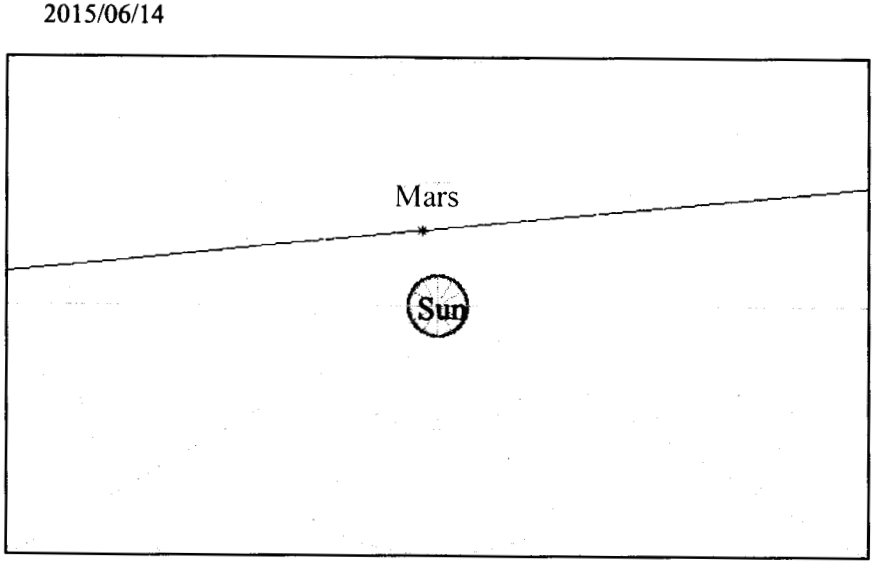
Cassini 2000 Solar Conjunction

Mars-Sun-Earth
Superior Solar Conjunction
Characteristics

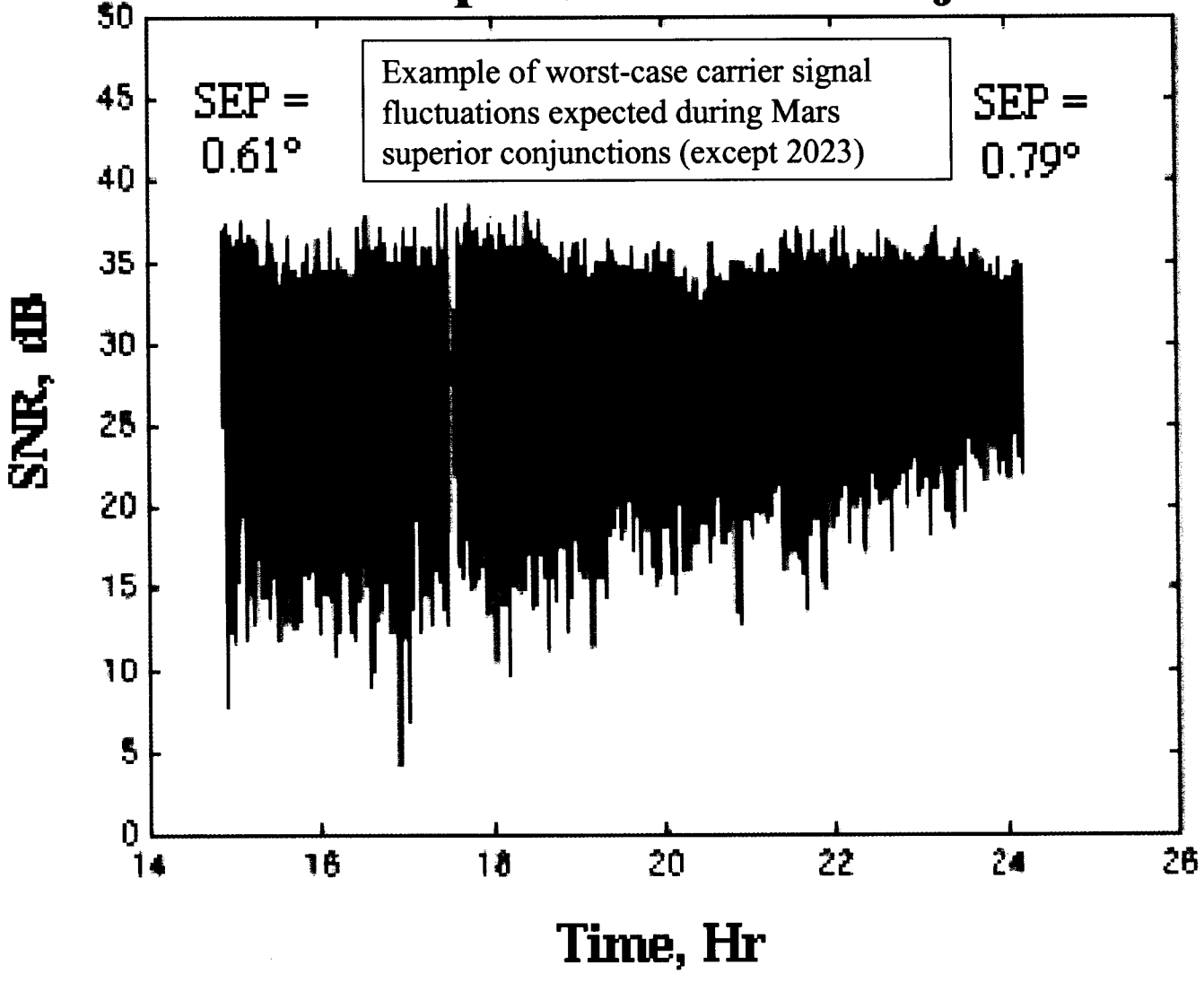
Conjunction Date Year/Mo/Day	Minimum SEM Angle	Minimum SME Angle	Expected Solar Phase	Solar Passage
2015/06/14	0.62°	0.40°	Minimum	North Polar
2017/07/27	1.10°	0.68°	Rise	North Polar
2019/09/02	1.08°	0.66°	Rise	North Polar
2021/10/08	0.65°	0.40°	Maximum	North Polar
2023/11/18	0.11°	0.08°	Maximum	Ecliptic
2026/01/09	0.94°	0.66°	Minimum	South Polar

Example of Mars-Sun-Earth Angles and Geometry 2015 Solar Conjunction





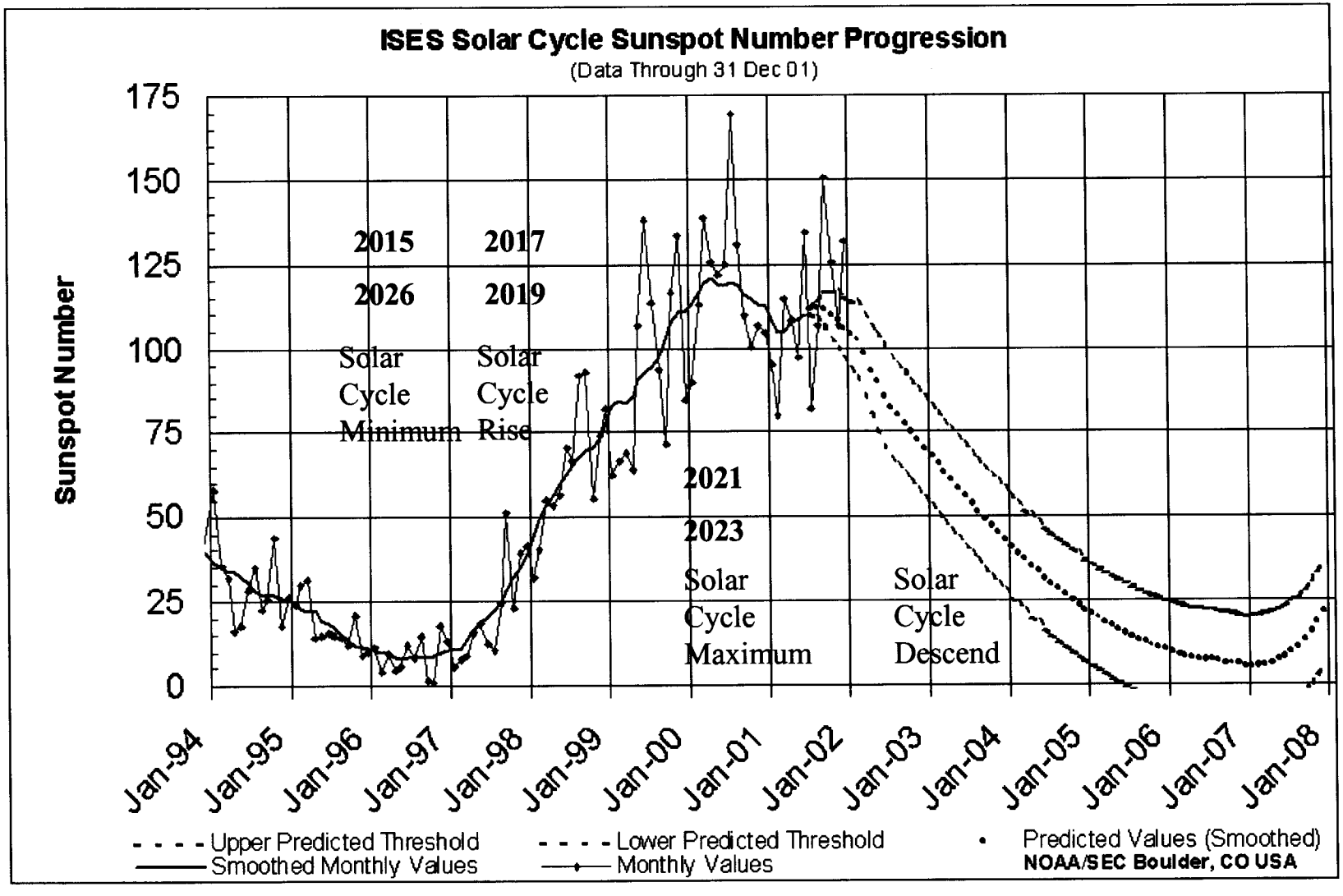
Cassini Ka-band SNR Data
2001/158 Superior Solar Conjunction



Ways to Optimize Data Return at Small SEP angles

- Use Ka-band
- Use FSK or Frequency Semaphores
- Use Spatial Diversity
- Use Frequency Diversity

Solar Cycle #23 and Expected Phases



Recommendations Using Ka-band

- For SEP > 1°,
  - Conduct passes normally
  - Ensure noise temperature increase due to solar effects is included in link budgets.
  - Widen receiver tracking loop bandwidths accordingly.
  - Select optimum data rate, coding, & frame size based on the conditions.
- For 0.67° < SEP < 1°,
  - Adhere to the above recommendations but also
  - Consider FSK and/or semaphores.
  - The lower limit may change depending upon solar conditions. The presence of solar events, sub-solar latitude and solar cycle phase should be considered.
- For 0.4° < SEP < 0.67°, (the realm of strong scintillation)
  - Adhere to the above recommendations, but also
  - Consider FSK or frequency semaphores with reasonable symbol duration for integration, and appropriate spacing in frequency.
- For SEP < 0.4°,
  - Account for system temperature increase as SEP approaches the disk edge of sun.
  - Consider semaphores with sufficient integration to counter increased thermal noise.
  - Consider taking a temporary communication outage during 2023 solar conjunction, when Mars is behind the solar disk (about one day), or below 0.4° (about 2 days),

CONCLUSION

By using Ka-band and a number of telecom signal techniques, it should be possible to maintain some degree of communication throughout all of the Mars superior conjunctions occurring between 2015 and 2026, except for 2023, in which actual occultation of the Sun's disk occurs.